SEEING ARCHAEOLOGY IN 3D: DIGITAL SPATIAL VISION

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ABSTRACT

3D digital archaeology is a growing subfield of archaeological practice. This paper assesses the role 3D archaeology in archaeological theory and practice employs, particularly in reference to the ways of seeing. Digital reconstructions themselves occupy a particular niche as manipulatable representations of archaeological contexts, enabling them to convey information and interpretation in ways previously impossible in the field. Using these new tools allows archaeologists to see spatial data in new ways and to therefore more fully explore and interpret it. Low cost methods of 3D model production, including new commercial structured light scanning device, are employed within previously excavated architectural contexts of ancient Pompeii to explore the feasibility and benefits of 3D archaeology's ways of seeing. 3D archaeology is shown to enable exploratory data analysis throughout the archaeological process.

BIOGRAPHICAL SKETCH

Alex Marko is a Masters candidate in Archaeology at the Cornell Institute of Archaeology and Material Studies, Cornell University. Mr. Marko earned his Bachelor of Arts degree with Distinction from the University of Nevada, Reno in 2008 in Anthropology with an emphasis in Archaeology. Mr. Marko is also the recipient of the Cornell Institute of Archaeology and Material Studies Research Grant and the Hirsch Scholarship.

Dedicated to Vesuvio, Bowie, & Little Buddy

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Introduction

The employment of digital visualizations is increasingly utilized as an essential component of archaeological investigations. Recent scholarship often suggests an increasing move toward the visual in contemporary society (Cochrane and Russell 2007: 5; Ware 2000; Gooding 2008) in both the popular and academic spheres.[1] A consequence of the increasing focus on the visual is increasing utilization of visualization as a tool of knowledge discovery and interpretation (Llobera 2011: 194). The burgeoning use of digital 3D archaeology has emerged as one of the most dynamic and potentially rich modes of visualization in archaeology. The goal of the implementation of visualization techniques is the rendering of data and information in ways that allow easy and comprehensive communication, insight, and understanding (ibid: 195). Digital 3D archaeology not only achieves these goals, but also offers further benefits for archaeological investigations through the processes involved in their creation. Digital 3D models inform modes of archaeological recording, interpretation, data management, experience, and presentation throughout the process of their creation and use as finished products (Earl 2013: 226-227).[2] The goal of this paper is to assess digital 3D modeling as an archaeological tool, particularly in regards to the impact it has had on archaeological ways of seeing. This relatively new addition to the archaeologist's toolkit is particularly beneficial to spatial studies given the nature of human interaction with and cognition of that class of archaeological data.

The ruins of ancient Pompeii present an ideal setting for discussions of the benefits of these new methodologies given the site's long history of archaeological study with particular emphasis on spatial dynamics. While early studies of Pompeii

[1] Cochrane and Russell state at the outset of their paper that they "at times choose to abandon traditional

[2] The influence of digital 3D models can, in some instances, be beneficial for its lack of a clearly defined end point. The interactivity and dynamism of methodologies associated with such models is discussed below.

focused on art- or architecture historical approaches, spatial studies at the site have come to embrace the notion that all behavior has a spatial aspect to it (Laurence 2007: 9) and thus have become more fully incorporated into the study of the city. As well as the spatial aspect of behavior there is also the impact of behavior on space, and a reflexive relationship exists between the two (ibid.). This relationship is not only persistently present in the Pompeiian context, but must also be understood to have been recognized and uniquely conceived of by the individuals that lived within those spaces (Wallace-Hadrill 1994: 4). Within the web of relationships between space, behavior, and identity, then, spatial studies allow opportunity to gain knowledge on past people and actions at a number of levels. The use of 3D archaeology as a tool of better understanding space at Pompeii (or any site) therefore has potential impacts on three distinct levels:

1. Individual sites or contexts within them
2. Archaeology writ large
3. Broader cultural ways of seeing

In the first instance, the incorporation of new methodologies for understanding space and the activities it housed and shaped offers new opportunities for the archaeological study of each space in which it is undertaken. By creating new tools of learning and introducing new workflows of study, 3D archaeology enables new data collection and interpretation to help decipher spaces and contexts. The second level of impact is on archaeology as a broader discipline, where multiple sub-disciplines function together to produce comprehensive narratives of sites and contexts (Khazree 2013: 440). Within this framework the various technologies[3] that define each sub-

[3] Khazree defines technologies here as "devised procedures, forms, categorization schemes not physical devices like scales or calipers," however the statement applies to technology in the more embodied sense as well.

discipline offer new opportunities for creating research agendas and seeing them through to the desired comprehensive narrative (ibid.). The introduction of new technologies in a field such as archaeology, then, allows new ways of recording data in addition to new ways of seeking out data and of understanding it. A large scale implementation of 3D archaeology within a broader archaeological field project would also create a more detailed record of the processes of knowledge acquisition and creation; 3D models based on real world phenomena record objects and contexts of study both in new ways and to new degrees. For example, the 3D visualization of each stratigraphic unit in an archaeological excavation would create a detailed spatial record of the excavation process and help in some way alleviate Mortimer Wheeler's adage that "archaeology is destruction" (1954). Finally, 3D archaeology, as an expression of a broader cultural movement to new tools of visualization, has broader impacts on the ways of seeing used in both sciences broadly and in relation to objects and spaces of cultural heritage. The use of 3D visualization has an epistemic impact, as scientific practitioners (in this case the 3D archaeologists) serve as gatekeepers of the "truth" (Knorr-Cetina 1988: 384) in their findings and in knowledge more broadly. By adopting new methodologies of presentation, 3D archaeologists can challenge existing paradigms of representation (for example, the published site photographs) as the standard means of sharing knowledge and install new paradigms that create more open and horizontal knowledge production.

Following a discussion of the benefits of this broader incorporation of 3D archaeology into the wider field of archaeological practice, a case study in the application of new, low cost methods of digital 3D modeling will explore methods of constructing and using digital 3D models. The case study, derived from work at the University of Cincinnati's Pompeii Archaeological Research Project: Porta Stabia

(PARP:PS), will focus on the employment of the Occipital Structure Sensor, a structured light scanning device (Occipital 2013), and AgiSoft PhotoScan, a software package that creates digital 3D models from still images. Both new technologies were incorporated into PARP:PS with the goal of assessing their functionality and practicality as alternate methods of implementing 3D archaeology as a method of recordation and interpretation in the field.

As an emerging field, digital 3D archaeology suffers from a lack of clearly defined terminology. The interdisciplinary nature of digital archaeology, which draws from many associated fields (i.e. computer science, information sciences, etc.) has further contributed to the imprecision of many archaeological discussions on the topic. Digital archaeology often adapts existing technologies rather than forging them anew (Huggett 2004: 82), leaving the ability to name specific techniques outside the purview of archaeological practitioners.[4] While individual terms have come and gone or been significantly altered in their implications,[5] discussion of 3D digital archaeology here seeks to convey a broad sense of both the processes and products of archaeological employments of digital technologies to represent three-dimensional spaces. Manferdini & Remondino argue that discussions of 3D modeling should include the entire procedure of data acquisition, data processing, information generation, and visualization (2010: 111-112). References to digital archaeologies in this paper also seek to engage with Forte's concept of cyber-archaeology, wherein not only digital reconstructions but also the processes of creating them and the feedback between digital objects and users are addressed (2008: 95). Therefore, digital archaeology is here

[4] Huggett characterizes archaeological acquisitions of new technology as "hand-me-downs" from other fields.

[5] The history of the term "virtual reality" is an excellent example: coined by French playwright Antonin Artaud in the 1930's, the term was either adapted or independently created in the 1980's in reference to artificial digital environments.

taken as an active and measurable virtual space that is used to study and compare datasets, models, and hypotheses *and* the interactions with that space (ibid: 97). Reconstructions and visualizations have long been utilized as addenda to fieldwork and research rather than integral components thereof (James 1997: 27). 3D archaeologies have the potential to not only create finished recompositions of architectural structures but also aid in the study of processes and relations between architecture, the environment, and the people that navigate them, particularly during the models' own process of creation (Watterson 2012: 21).

Tradition and Critiques

Despite its reliance on relatively or absolutely new technologies, 3D archaeology is firmly situated among established archaeological traditions for viewing. Archaeology has, for instance, a long tradition of physical modeling as a means of developing understanding and conveying conclusions (Earl 2013: 227). A notable example of traditional modeling is the "Plastico di Roma Antica" at the Museum of Roman Civilization (Museo della Civiltà Romana). The "Plastico" was constructed by Italo Gismondi from 1933 to 1974 and sought to fully reconstruct imperial Rome at a 1:250 scale (Guidi et al. 2005). This model sought to combine the work done on the city's imperial age to present a single coherent vision of Rome's layout in the age of Constantine. Digital modeling, on the other hand, has been employed in the field for such disparate uses as qualitative assessment and quantitative simulation (Earl 2013: 229). Many uses of 3D archaeology have sought to be scientific in their accuracy, as seen in the attempt to create profound mimesis through metrically accurate and objective reconstructions (Gillings 2005: 235). At the same time, the very same representations can be used to understand contextual situation in the past (Earl 2013: 234), thereby emphasizing interpretative utilizations as the primary benefit of 3D archaeology. These connections with existing archaeological paradigms inform the ways of seeing employed by the digital archaeologist in conjunction with the tools of 3D archaeology and the representations they enable.

The adoption of new technologies is often met with resistance in academic disciplines and archaeology, at times a conservative field, is no different. Walter Benjamin wrote critically of new media and its impacts on objects of cultural heritage, namely in reference to mechanical reproduction (through photography) and the loss of the presence and aura of an original object, as far back as the 1930's (Benjamin 1969). Concerns with the encroachment of high technology are perhaps best summarized by Jeremy Huggett's article "Archaeology and the new technological fetishism" (2004). Though decidedly not in direct opposition to the incorporation of new methodologies and tools, Huggett raises concerns with the implementation of the new for the sake of its newness. Among potential pitfalls for the use of 3D digital archaeology listed are:

> data may be wrenched from context, argument separated from evidence, interpretations transformed into "facts", explicit knowledge separated from tacit knowledge, [and] push-button solutions substituted for knowledgeable actions. (Huggett 2004: 84)

The lack of knowledge about any process, digital or otherwise, is sure to have negative impacts on the researcher's ability to take full advantage of the opportunities it presents. While archaeologists adopting new digital tools and methodologies should take these concerns seriously, the full incorporation of 3D archaeology into the archaeological process is the best means of building competent practitioners that fully understand the theoretical and practical issues of the new approach. Researchers that employ bleeding edge technologies often fall victim to theoretical lag, whereby new technology is used despite not fully understanding its processes or theoretical implications (Hand & Sandywell 2002: 250). Rather than steering clear of new methodologies, however, archaeology will benefit greatly by more fully engaging with them to build understanding of techniques and their impacts on research. Critically engaging with and fully understanding the applications and limitations of (often hidden) digital processes avoids the "abdication of authority" (Huggett 2004: 83) to those often complex and novel tools.

New tools, methodologies, and theories are not the only potential threat in the seizure of authority from researchers. In the case of material culture, landscapes, and the other phenomena seen by archaeologists, viewing is structured and mediated by the tools of archaeological practice and by the classifications that organize cognition (Goodwin 2001: 168), be they cutting edge or traditional. For the field of archaeology, these mediations come in the form of field tools, laboratory technologies, and office spaces that comprise the stuff of archaeological inquiry from conception to publication. The slow uncovering of an artifact one trowel scrape at a time or the organization of perceptions (such as through use of Munsell Soil Color Books or generic field recording forms), among many other practices particular to the field, condition both the act of viewing itself and the practices that surround and enable it. The recordation of archaeological sites and artifacts, which often includes the use of complex visual representations, becomes a barometer of the systems of thought that greatly impact our perceptions and study of the past (Arnold 2005: 92). The creation of these scientific images is also a key component in the creation of the scientific self (Daston & Galison 2007: 363); ways of seeing utilized by a particular community of practice are conveyed through representations in order to both spread data *and* to spread a sense of the seer. A lack of critical engagement with any aspect of the archaeological process poses a threat to the researcher's authority over structure and content. Rather than avoiding or removing any potentially problematic aspect of archaeology as a discipline, practitioners in the field can make full use of them by remaining aware of the influence they may exert.

The use of 3D archaeology offers the ability to challenge existing paradigms of representation within the field in both practice and theory. Digital 3D creates simulations of real space that reflect what Baudrillard refers to as their "genetic miniaturization"; spaces can be reduced to cells, matrices, memory banks, or models that can be then used to recreate the original infinite times (Baudrillard 1994: 2). Perhaps the most pertinent example of this process is the construction of point clouds that create the framework of both imaging technologies discussed here. In the point cloud, real world spaces are conveyed as densely packed clusters of individual points that represent geometry/structure of a scene (Verhoeven 2011). These points may be conceived of as the cells of Baudrillard's miniaturization process (**Figure 1**); in theory, a dense enough digital point cloud coupled with a large enough 3D printer could produce an exact replica of the site. In the field of archaeology the assertion that the real and a simulation are entirely equivalent falls flat in the face of material studies and materiality, particularly considering what Hodder calls the "ever-present force of things" (2012: 215). Meaning is not only derived from the existence of a site of cultural heritage, but largely stems from performance at the site (Bruner 1994: 409). Similarly, performance of and within spaces creates meaning in their original phase of occupation and use. While a simulation cannot recreate the history of an object or space (the agency of its creators, its own agency, its history, its relationships with human and nonhuman alike), the move toward simulation in 3D archaeology nevertheless creates new opportunities for seeing in two important ways: first, new vantages are created that are otherwise impossible[6] and second, contexts that do not exist in the real world can be visually experienced[7] As Merleau-Ponty said, "what you see depends on where you sit" (1962: 78) and one can "sit" anywhere in a digital simulation.

Three-dimensional imaging in archaeology began with the use of stereo photography, which Nicholson characterizes as "Victorian virtual reality" (2001: 402). The use of computers in archaeology was initially a separate endeavor from imaging, as seen in James Deetz's computerized analysis of Arikara ceramics (Deetz 1965). Indeed, much early discussion of computing in archaeology was almost entirely focused on statistical analysis (Lock 2003: 10). Paul Reilly first introduced virtual archaeology, as we know it today (the use of 3D computer models of architecture and artifacts), in 1990 through a presentation and video animation at the Computer Applications in Archaeology Conference (Barceló et al. 2000). Interest in the possibilities of digital archaeology grew quickly, with institutions such as the University of Arkansas' Center for Advanced Spatial Technologies (CAST) (established in 1991) and the University of Southhampton's Archaeological Computing Research Group (established in 1994) leading the way in many digital archaeological endeavors. The increase in use of computers in archaeology follows a broader movement away from modernism grounded in calculation to the post-modern culture of simulation and complexity (Lock 2003: 12); computers began to be used not as atheoretical statistical machines but became fully enmeshed in archaeological practice and theory. Digital 3D methods have long been used to study both objects (archaeological artifacts) and spaces (archaeological sites), though became widely available in the 2000's with the

[6] These vantages could include views that are normally impossible (such as aerials views that could not normally be accessed or even views from beneath peering into a structure).
[7] Contexts such as viewing a segment of a larger object or context in isolation or selectively adding or removing components.

advancement of associated technologies (Milojevic et al. 2005: 1036-1039). Recent years have seen further growth in the use of and engagement with 3D archaeologies.

Ways of Seeing

Ways of scientific seeing are constructed of corporeal skills and cognitive stances that intersect and interweave throughout the physical and ideological realms of inquiry (Daston & Galison 2010: 369). Historicized collective ways of seeing serve as a key component of the epistemology of a given discipline, thereby shaping the knowledge it produces (ibid.). Goodwin argues that archaeologists, as an example, create a community of competent practitioners who are expected to see the world through the relevant work, scenes, tools, and artifacts that constitute their profession (2001: 174). In order to function as a coherent school of thought and practice, archaeology relies on ways of seeing that are firmly situated in a particular social community that allows for mutual intelligibility. Properly conditioned ways of seeing, Goodwin continues, are expected of any competent archaeologist (ibid.). Rather than serving as evidence in empirical or interpretive applications, however, ways of seeing define what evidence is (Daston & Galison 2010: 369).

The expansion of the repertoire of scientific instruments that produce and present visualizations require practicing members of a community of viewing to learn to see anew (ibid: 22). The introduction of photography, for example, enabled new modes of representing traditionally visible phenomena while at the same time allowed for the study of the previously invisible (such as ultraviolet light) (ibid.: 126). Early forms of photography were initially seen as exact and precise replicas of original objects, though as the photograph became more widespread it was increasingly questioned (Snyder 2004: 202). Even if photographs were taken to be direct replicas of a scene, some critics observed that they were incapable of having, and therefore of conveying, experiences of the sights they capture (ibid.: 210). This view is best represented by Walter Benjamin, who noted "that which withers in the age of mechanical reproduction [read the age of photography] is the aura", or the quality of an original object's presence (Benjamin 1969: 221). The U.S. court system came to view photographs as analogs of human vision (itself a photograph captured on the retina), and therefore accepted photographs as accurate texts that bore no affect of memory (Snyder 2004: 220). 3D modeling allows for a different experience of places and objects, however. Fully 3D representations allow a richer visual experience of place or object by presenting greatly increased potential locations from which to view them (Paliou et al. 2011: 384). While the direct experience of an object cannot be completely replaced, 3D models allow a more robust experience than photographs due to their ability to simulate multiple aspects of real world encounters (adjustable lighting, varying perspectives, etc.).

New instruments need not be specifically oriented toward the visual to impact ways of seeing, and therefore advancements in science can often more broadly contribute to new opportunities in archaeology (Pollard & Bray 2007: 248). An example in the development of archaeological ways of seeing from scientific advancements is seen in the ability to build reliable chronologies brought about by the radiocarbon revolution (Renfrew 1970: 207-209). This advancement created new kinds of evidence in archaeology (C_{14} atoms, for example) and caused archaeologists to see existing forms of evidence in new ways; archaeological artifacts became situated in specific and scientifically knowable chronological positions.[8] 3D archaeology serves to introduce

[8] The construction of these chronologies has a long history and, with it, number of caveats. While neither will be discussed at length here, Pollard & Bray 2007 offers an excellent summary of the iterative process of developing radiocarbon dating.

another suite of instruments and interpretive tools that ultimately impact the ways of seeing employed in the wider discipline.

3D archaeology is a key new tool being adopted in the field by practitioners that seek to employ modes of visual expression that are both active and dynamic (Cochrane & Russell 2007: 8). 3D archaeologies achieve this aim by transcending the limitations of two-dimensional archaeological representations (ibid.), such as limited interactivity and static vantages. Archaeology has long recognized the importance of recording artifact find locations and sites in three dimensions, though 3D representations of that data have largely been confined to (well funded) media publication often aimed at non-academic audiences (Earl 2005: 204). Advancements in 3D acquisition techniques, however, have expanded the potential utility of digital representations, particularly in the creation of reality-based models (Guidi et al. 2014; Manferdini & Remondino 2010). This move toward digital 3D models built directly on spatial data captured in the field marks a significant departure from early incarnations of 3D archaeology, which largely functioned as reconstructions rather than records (Earl 2005: 206). The increasing use of reality-based models has not replaced other more speculative (re)constructions, but has instead expanded the field of potential digital tools.

Reality based 3D recording creates metrically accurate representations of archaeological features and contexts in their current condition (Guidi et al. 2014). These representations open new possibilities for ways of seeing throughout the archaeological process. The application of such models firstly establishes a greatly enhanced record of archaeological sites and processes. Sites recorded in three-dimensions include a field of spatial data previously either lost or difficult to convey. Comprehensive 3D models, which are increasingly feasible with technological advances, also record spatial data that is not specifically targeted by archaeologists.[9] The ability to indiscriminately capture data creates massive spatial datasets that would previously have been prohibitively expensive or impractical (Cripps 2012: 42). Reality based 3D recording technologies have advanced to the point that digital archaeologist Bernard Frischer has claimed "we can study both Nature and its digital representation with equal confidence" (2011: 29).[10] Given this view, 3D archaeological representations could be said to transcend the category of images, as instead of being merely sight(s) that have been recreated (á la Berger 1977: 9), they are fully constituted objects in their own right that contain both visible and extrasensory data. Frischer still emphasizes the role of metadata and documentation in the presentation of digital models, however, which shows recognition of the interpretive elements present in all such reconstructions (Frischer 2011: 29). If a representation were a true 1:1 copy of the original, metadata would become inconsequential as there would be no interpretive nor structural framework, simply a completely true (read objective) representation. Cripps argues that despite high degrees of accuracy, 3D archaeologies do not create facsimiles of archaeological sites and that interpretation remains an essential component of digital models (Cripps 2012: 42). Indeed, it is largely agreed upon within the field of archaeology that any archaeological investigation contains a degree of interpretation no matter how empirical it seeks to be (Llobera 2011: 214). The value of digital 3D models is not the creation of 1:1 copies of the physical world, but rather that of new perspective and vision for empirical data and interpretations; 3D archaeology creates previously unexplored archaeological hermeneutics (Forte 2014: 27).

[9] This statement should be qualified as a matter of degree; archaeologists still only record the spaces in which they employ recording technologies, however 3D data can be obtained of every object within the capabilities of the device in that space, regardless of specific targeting.

[10] Frischer here refers to "Nature" as a concept situated in western thought from the ancient Greek world onward. "Nature" consists of all reality outside of human arts and sciences, which themselves are attempts to understand the natural.

3D representations also allow for a new degree of manipulability, allowing dynamic viewing of site and artifact spatial data (Cochrane & Russell 2007: 8). This degree of manipulability creates a distinction between the representations created by 3D archaeologies and Berger's construction of an image as a static "sight that has been recreated" in his seminal *Ways of Seeing* (Berger 1977: 9). The lack of a single vantage point in a virtual reconstruction suggests that it recreates an environment rather than only a sight thereof. Further, the ability to indiscriminately capture three-dimensional data may lead to the inclusion of sights never actually directly perceived by the original modeler. 3D reconstructions also exist between Berger's definition of drawings and photographs. He describes the former as a translation wherein a representation is made through conscious choices of the artist and the latter as the reception of a representation from the light emitted by an object (Berger 1989: 94-95). While it is possible for 3D models to be entirely constructed by conscious decisions of the modeler, the use of reality capture techniques receives light data that is then used to derive spatial data through algorithms and calculations. The 3D model also does not neatly fit Berger's mold of a film, which he characterizes as a reproduction of images that leads the spectator to the filmmaker's own conclusions (Berger 1977: 26). Rather than dictating a single course of viewing, however, interactive 3D models create the possibility of infinite courses through various perspectives. It is possible to constrain the viewer's perceptions, such as by fixing the perspective to the predetermined eye height of a "playable" avatar in the simulation (Frischer & Fillwalk 2012: 51),[11] however even within

[11] In the case of the Digital Hadrian's Villa Project cited here a "scientifically accurate 3D reconstruction" was created within the Unity3D videogame graphics engine. This reconstruction can be explored in a number of ways, including through 1st and 3rd person perspectives of avatars of the viewer's choosing (Frischer and Fillwalk 2012: 51).

this constraint viewers are free to explore and create new vistas in ways that are impossible with static images.

Thinking Spaces

3D archaeology is not only useful in its ability to accurately record and portray three-dimensional spaces, but also in its application as a tool of reconstruction. Reconstructions of 3D data can be built on frameworks created by reality based models, constructed of historic data, or based on other information sources or combinations of any of the above (Guidi et al. 2014). Reconstructed models can be utilized as "thinking spaces" for archaeologists through which models are used for visual stimulation, as a conflation and reasoned extrapolation of archaeological data designed to spur contemplation of datasets (Earl 2013, pg. 234; Cripps 2012: 41). Digital models can help to bridge observations and interpretations by serving as "reasoning artifacts" (Llobera 2011: 214). Reasoning artifacts, such as digital models or other visualizations, make massive amounts of data readable, to illustrate the results of a model and make them more intelligible, and to render part of an argument visible (ibid.: 194). 3D models allow for a deeper knowledge of spatial data as it communicates an important aspect of the archaeological environment that was previously difficult to access in the interpretive tools produced by archaeologists (Forte 2008: 98). Thinking spaces can be utilized to explicitly test hypotheses or to simply explore the spatial data visually. Either of these approaches contributes to the incorporation of exploratory data analysis in archaeology. Exploratory data analysis, a conceptual framework for analysis based on the work of John Tukey, seeks to develop a deeper understanding of a given dataset, generate new hypotheses, and identify patterns in data with limited predetermined structure (Pertl and Hevey 2010: 456). This type of analysis is not based on a particular methodological approach, but rather is the pursuit of constructing and interacting with datasets in ways that allow (or even encourage) new lines of inquiry rather than simply confirming or negating existing questions. The processes of exploration and confirmation are not mutually exclusive; therefore, exploratory data analysis should be viewed as an additional stage of investigation. Archaeological investigations also, it should be noted, include an exploratory component by their very nature as a quest for the uncovering of the deposited material culture of the past. The value of an exploratory data analysis framework in archaeology lies in the structure of recorded data and ways in which it can be interacted with; 3D models avail intricate spatial and contextual recording in dimensions (literally and figuratively) previously inaccessible to archaeologists. This dynamic framework not only allows for the testing of hypotheses but also encourages the formulation of new questions through the "development of rich mental models of the data" (ibid.: 456) at the core of exploratory data analysis.

The tools of archaeological recordation impose specific perspectives on datasets and thus constrain the potential for interpretation (Khazree 2013: 441). The effective application of 3D models as thinking spaces, however, is a means for recording and presenting datasets that expands (or, idealistically, transcends) many of these limitations. While 3D archaeology remains bound to the structures of metadata and ontology like any other method of data collection and interpretation, it also creates previously impossible bridges between archaeological datasets and interpretations. For example, 3D models can simultaneously contain the real and the reconstructed and can use hypermedia linkages to connect metadata, data, and interpretation in new ways (Forte 2008: 103). The flexibility of 3D models also enables simultaneous function as generic and analytic database, which Khazree defines as those structured for data management and data analysis respectively (Khazree 2013: 442).

The role of 3D models as reasoning artifacts speaks to the reliance on visibility as a means of conveying data; what can be seen is privileged as true above that which is only thought or believed (Amman & Knorr-Cetina 1988: 135). Seeing, however, is socially constructed, particularly within communities of scientific practice (ibid.), which are themselves built on a shared belief of what it is to "see" as a member (Goodwin 2001: 168). The use of 3D models to extend an ability to see archaeological contexts or objects that would otherwise be difficult (i.e. politically or economically unfeasible) or impossible (i.e. excavated strata that were destroyed in the archaeological process), leading to new abilities to independently confirm or deny the claims of researchers. Thus, 3D models could be reasoned through both during fieldwork and afterword in interactive ways that are not hegemonically structured. Further, these models allow a more immersive and heuristic experience of places and thus provide new opportunities for hermeneutic interaction (Forte 2014: 2).

The thinking space model is not only an example of a new way of seeing in the field, but also speaks to changes in archaeological practices of seeing. The incorporation of new visual tools creates spaces for the ongoing production of particular kinds of action in the archaeological process (Goodwin 2001: 171). New modes of seeing are becoming ingrained in archaeological practice, thus creating new situationally contingent ways of seeing. In the case of 3D archaeology, digital recordations and reconstructions create a mode of seeing mediated by the screens of our digital devices and the code that allows them to operate. The wide cultural impact of digital modes of seeing on our everyday lives inevitably bleeds into archaeological practice (Huggett 2004: 81). The field of archaeological practice should recognize these new ways of seeing through the virtual as a dense visual resource with the capability to convey augmented information (Forte 2008: 95).

Digital thinking spaces can be used to test multiple aspects of a hypothesis' success or failure simultaneously. For example, a reconstruction of Rome's Ara Pacis and nearby Horologium of Augustus serves as an example of both levels of engagement available through 3D models as thinking spaces. An interdisciplinary team created models of the two monuments[12] in order to test Buchner's hypothesis that the Horologium of Augustus was constructed in order to cast a shadow that perfectly aligned with the entrance of the nearby Ara Pacis on the Emperor Augustus' birthday (Frischer 2013a). Using celestial data produced by NASA to accurately model the position of the sun in the sky of September 23rd, 9 BCE, the researchers showed the hypothesis to be incorrect. However, the model was then used to find a series of dates that would produce the desired affect, leading to the development of research questions regarding the significance of those dates in this context. Further still, the use of a contextualized reconstruction allowed a simulated phenomenological experience of the event that showed that the alignment of the sun above the Horologium from the vantage of the Ara Pacis on these days is equally as likely to be the desired outcome as the alignment of shadow (Frischer 2013a). Through this process we see the testing of a hypothesis, the discovery of alternate conditions under which that hypothesis could be partially correct, and a new perspective on the significance of an ancient event. In a similar study of solar alignment at Hadrian's Villa, the researchers stress that their models can be "used in a purely heuristic way to explore the villa with no preconceived notion of what will emerge in the hope that new, hitherto unsuspected alignments may result" (Frischer and Fillwalk 2012, pg. 53). Solar alignments are but one avenue of exploration in a virtual environment, as other studies have focused on topics as

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[12] This model also created the proper spatial position of the objects in antiquity, as both monuments have been moved from their original locations in modernity.

disparate as the placement of wall paintings in Çatalhöyük (Earl 2013) to the movement of past people within Iron Age British houses (Woolford & Dunn 2013).

Spatial Learning

The nature of digital models also allow for what is essentially infinite experimentation with ways of seeing an archaeological context or object (Earl 2013: 230). This expansion of the potential avenues of visual investigation have significant impacts on the ways of seeing employed by archaeologists. This is particularly true of spatial data, as the creation of rich virtual environments through 3D models enables levels of recordation and interaction that were previously impossible. Spatial knowledge is built through perceptual-motor interaction with environments (Forte 2008: 95), and virtual environments can in many ways replicate the experience of real-world spaces. Perceptual-motor knowledge can be acquired directly through interaction with the world or indirectly through external representations (Montello et al. 2004: 251). Virtual environments are a way to bridge these two categories, as they are symbolic representations of the real world, yet are also interactive, real-time, and three-dimensional and are able to respond realistically to the simulated motor behaviors of users (ibid.: 256). Digital archaeologies seek to reconstruct spatial relationships in a way that reconnects the real world with the map (the direct to the indirect) (Forte 2008: 97). The process of learning spatial information from digital 3D models is similar to learning from real-world interaction as virtual environments preserve many visual-spatial characteristics, such as perspectives of viewing (Richardson et al. 1999: 741-742).[13]

[13] Virtual environments cannot fully replicate experience in the real world, though, and differences remain in some aspects of spatial knowledge acquisition. For example, distance and size are often underestimated in 3D models (Richardson et al. 1999: 742). However, simple single-floor virtual environments may be able to convey as much knowledge as the real environments they represent (ibid.: 748).

The benefits of 3D digital archaeology are not simply in the recreation of space and knowledge, however, but also in the ability to open new avenues of learning and exploration. Digital environments produce new models of knowledge and new interpretive processes in addition to their recreation of real-world environments (Forte 2008: 95; Manferdini & Remondino 2010: 110). 3D models enable researchers to quickly engage with large and complex datasets in ways that can identify unexpected new information or help make explicit problematic aspects of data or interpretations (Earl 2013: 239).

The accessibility and interactivity of 3D archaeology may well shift the loci of various analytical and interpretive endeavors in archaeology. Digital 3D models enable enhanced capabilities to study archaeological contexts after fieldwork has concluded. Virtual environments create feelings of immersion in the real-world spaces they recreate through the multisensory involvement of the user in 3D space (Forte 2008: 95). The measurement or identification of attributes can be automated (through properly written code) to expand the scope of analysis both within and between archaeological projects. The heuristic component of archaeology can, with digital representations and reproductions, be extended into the home office, as well as the archaeological site. Digital representations create new dynamism in viewing, analyzing, interpreting, and presenting the materials under study in an archaeological project.

Dwelling in the Porta Stabia: Digital Spatial Experience at Pompeii

The Pompeii Archaeological Research Project: Porta Stabia (PARP:PS), directed by Dr. Steven Ellis of the University of Cincinnati, has a longstanding commitment to the incorporation and refinement of digital archaeology, including the documentation of spatial data in three-dimensional virtual environments (Ellis et al. 2011; Ellis et al. 2012; Wallrodt et al. 2013; Tucker & Wallrodt 2013; Motz & Carrier 2014). The project's pioneering use of iPads for field recording (Motz & Carrier 2014: 25) is an important example of this commitment, though from its inception PARP:PS has sought to document spatial data in digital 3D environments through the use of CAD (Tucker & Wallrodt 2013). The existing CAD documentation program was supplemented and expanded to include the Structure Sensor and AgiSoft PhotoScan. These technologies were incorporated into PARP:PS as alternate methods of implementing 3D archaeology as a method of recordation and interpretation in the field.

The Occipital Structure Sensor, a newly released digital 3D scanning device, uses a laser projector to cast a precise pattern of infrared dots onto objects and spaces, which it then records via a frequency matched camera (Occipital 2013). The way in which these light projections deform over three-dimensional surfaces is interpreted by associated software to calculate depth from the sensor, which allows a 3D model to be generated (White 2013, pg. 180). The Structure Sensor is designed for 3D mapping of indoor spaces, object scanning, the creation of virtual environments, and many other potential applications (Occipital 2013). The Structure Sensor is operable from 40cm to 3.5m from the surface to be recorded and has a typical precision of 1% of the measured distance (ibid.).[14] The Structure Sensor is currently in an early stage of release and the potential applicability of the platform to archaeological projects is likely to grow as software develops alongside the device. Occipital has produced an application that allows the device to view and record depth in full color and in infrared; however, the device can also make use of existing software for structured light scanning such as Skanect. Finally, the device can be used to measure 3D objects and spaces and creates

[14] The Structure Sensor is therefore able to record a 3D object from 40cm away with a margin of error of roughly 4mm.

editable models (Reis 2014), both of which have applications for archaeological recording and interpretation.

AgiSoft PhotoScan is a more widely recognized and utilized tool for the creation of 3D models in archaeology (Forte 2014; Verhoeven 2011; Roe 2010). The software utilizes the structure from motion technique, which allows the reconstruction of three-dimensional scene geometry and camera motion from a sequence of two-dimensional images captured by a camera moving around the scene (Verhoeven 2011: 68). The data captured through still images is utilized to create multi-view stereo-reconstructions, which can then import surface texture data from the initial photographs onto the generated point-cloud mesh to create detailed 3D models of real world spaces (ibid.).

AgiSoft Photoscan was used to produce a dense point cloud model of a particularly interesting architectural space within the PARP:PS project area: Inusla I.1.1, Room 2 (**Figure 2**). The room is most notable for containing an early public well within the city wall that, after an extensive period of use, was privatized in the early first century CE (Ellis et al. 2011: 5). The model was created using 136 still images of both the interior and exterior of the room (**Figure 3**). In order to further emphasize the accessibility of this process, an iPhone 5s was used to capture still images for the process.[15] PhotoScan automatically derives necessary information about the camera used from each photo's associated EXIF data (which is also useful for those that seek to further explore the metadata of the photographs they have taken). The photographs were aligned to create the initial model of the space (through a sparse point cloud), and then used to build a dense point cloud, a general and detailed mesh of the point cloud, and a surface texture image. Perhaps the most immediately apparent benefit of the

[15] Though admittedly a pricey device in itself, the use of a smartphone camera shows that 3D archaeology can be done with the tools that may already be in one's pocket, much less at a field project as a whole.

PhotoScan process is that it produces a metrically accurate[16] photogrammetric reconstruction of space. In the case of the exposed walls of Pompeii, this enables numerous avenues of study; volumetric study, detailed measurements of individual components or sections that would be very time consuming in the field, etc.

In addition to practical explorations, the model allows new opportunity to think about the space. Photoscan is able to produce orthophotos of the models it builds, thereby creating vantages that are impossible without other specialized equipment (in this case, only a ladder was needed to capture the top of the standing walls, which the program can use to recreate the wall tops from any vantage). The space can also be altered in the digital realm to help understand it better. In this case, the doorway in the western face of the room containing the well can be digitally unblocked to allow new lines of site (**Figure 4**). This new view of the structure shows that the narrow blocked doorway, likely designed to control access to the interior space in a particular way, also severely limits visibility of the remainder of property I.1.1 from the doorway leading to room 2 (**Figure 5**). This observation, new at least to this author, shows the unexpected benefits of digital 3D heuristic exploration.

While PhotoScan is an established archaeological tool with a rapidly growing following, the Structure Sensor is a new entry to 3D archaeology. The device (and particularly its associated software) could still be considered a beta, as it is at present only available to backers of the founder's Kickstarter[17] crowd funding program. Despite the early stage of its release, the Occipital Structure appears to hold great promise for 3D archaeology. At present, the options for software to operate the device include a

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[16] In one case study, a model constructed of only 10 photographs had a maximum error of 7mm when compared to total station data (Doneus et al. 2011: 83).

[17] Kickstarter is a "crowdfunding" platform wherein proposed projects raise capital through donations from online donors once a minimum funding goal has been pledged.

"sample" scanning application for iOS devices and Skanect, a program previously designed to use the similar technology of modified Xbox Kinect devices to record three-dimensional spatial data. An immediate shortcoming in both options is the lack of ability to record in color, though this problem is slated to be resolved in a pending software update. Initial explorations of the device's ability show that, while unable to record some small features at any distance, a careful scan of ancient walls creates a detailed enough model to differentiate between individual stones in an opus incertum wall.

The iOS "Scanner" application released by device maker Occipital is the easier to use method of scanning with the structure, however the program is limited in its capabilities. "Scanner" functions by scanning all objects in a user-defined three-dimensional cube of space. Given the devices maximum advertised range of 3.5m, this mode is difficult to use to scan entire rooms (particularly when trying to acquire data on both sides of the roofless walls of ancient Pompeii). The Scanner application works best for medium to large objects (such as an adequately detailed model of a chair). The Scanner sample application impresses most with its speed, as the program builds models in real time with little to no noticeable lag between device movement and model creation.[18]

Skanect offers more in-depth opportunities to scan using the Structure Sensor by passing on the task of processing data to a laptop computer on a shared Wi-Fi network. While few archaeological sites can be expected to come furnished with wireless networks, a network created on a laptop in the field was easily strong enough to operate beyond the device's range. Skanect offers options for building models of

[18] For example, the "Scanner" application was able to 3D model a moderately compliant stray dog that lives within the ruins of Pompeii before she moved enough to affect the device's tracking ability.

"Body", "Object", "Room", or "Half-Room" and can be set to gather data within a space ranging from 0.1 to 12 meters. Scanning in conjunction with another device requires slower and more deliberate movements, but the interior of I.1.1 room 2 was still scanned in less than 5 minutes time (**Figure 6**). The resolution of the Skanect model is lower than that of the PhotoScan created version, as the former contains 230,136 polygonal faces in its mesh while the latter consists of 4,352,382.[19] The main downfall of the Occipital Structure and its associated software options, however, is the device's inability to capture spatial data in bright sunlight. Property I.1.1 is one of only a very few spaces within the PARP:PS project area that receives shade during a significant portion of the day, even with the luxury of tall standing walls that so many archaeological excavations lack. The sensor appears to be overwhelmed by the natural infrared light of direct or reflected sunlight and simply sees stone in direct sun as a void.

The Structure Sensor is, at present, a promising new device that has great potential for expanded utility within archaeological projects. The models it produces are of a high enough quality to accurately convey spaces and context that fall within its operational parameters. The pending inclusion of color data will greatly further the Structure's applicability to archaeological investigations. The products of the sensor's structured light scanning can certainly be utilized as thinking spaces where at least aspects of a 3D real world space become more highly accessible and manipulatable than real world experience with delicate and protected sites of cultural heritage.

The potential uses of a PhotoScan, Structure Sensor, or any 3D model are far too many to enumerate fully here, however the exploration of some examples here

[19] Even considering the larger space covered by the latter model, the difference is clear.

illustrates the epistemic shift that their incorporation can cause in the field of archaeology. The particulars of this space are fascinating given its likely important role in Pompeiian civic life as well as its highly unique circumstances in Pompeiian and wider Roman spatial studies. Such particulars, however, are better served through the extensive publications pending from the PARP:PS team. Taken broadly, however, 3D archaeology undertaken within Pompeii has potential to drastically alter ways of seeing related to Roman spatial studies. Space in Roman urban environments was planned, but only in the sense of how a city should be laid out rather than in the modern sense of strict regulations, planning boards, and zoning (Laurence 2007: 11). Pompeii's spaces are the result of social processes that took place over centuries (Laurence 2007: 17); properties expanded and contracted, walls were built and removed, and rooms could switch from one owner to another (for many examples of the frequent changes of Pompeiian vernacular space, see Ellis et al. 2010 & 2011). As one studies the standing architecture that remains at Pompeii, however, the view is very different. The walls of Pompeii today are fixed and unmoving, all (rightly) the target of extensive programs of maintenance and upkeep. 3D archaeology allows these spaces to be conceived of and, perhaps more importantly, seen in their original way. Digital spatial models allow the many incremental changes of urban development to be peeled back before our eyes in ways that allow new discovery and analysis.

Publication and Sharing

In order to maintain transparency in digital methodologies, archaeologists can indicate the accuracy of the representations they create in terms of underlying information and interpretative processes (Earl 2013: 232). This responsibility is particularly important in relation to representations as complex as 3D models. The process of interrogating one's own methods is itself integral to forming new hypotheses and testing them. This need gains even further importance in the implementation of new methods, and in digital methods specifically where archaeologists must often work with tools and programs designed by specialists outside of the field. One means of illustrating the accuracy of a model and achieving transparency in 3D modeling is the inclusion of metadata and paradata in publications. Publication itself also poses new problems for the digital archaeologist, though efforts are currently in process to address them.

Metadata and paradata are not new concepts, though the introduction of digital modeling and other new methods in many ways changes their form and prevalence. Taken broadly, metadata is simply data about data. Paradata is a particular subset of metadata related to the process of recordation of a given dataset. This class of metadata includes information on methods used, observations of the recorder, and their questions and assumptions (Frischer 2013a). Paradata can be shared in a variety of ways, including traditional publication techniques, hyperlinked within the model itself, or simply published on a project website (Frischer and Fillwalk 2012: 51) alongside the models themselves. This class of information has always been integral to models and reconstructions in any medium yet may become more prominent due to the complexity of digital models. The full incorporation of digital methodologies throughout the archaeological process will aid in both the production of robust meta- and paradata records and in fostering better capabilities to understand them among archaeologists.

Publication of 3D models presents new challenges to archaeologists, whose academic output has been dominated by text from the field's inception. As the practice of digital modeling is relatively new, there is a stark lack of the infrastructure needed to collect, review, preserve, and distribute this previously scarce or absent medium (Koller et al. 2010: 7:3). While in many instances 3D models have been published through screen captures or presented as videos, these methods limit the interaction between models and those outside of the research teams that produced them. This lack of interaction makes impossible the heuristic exploration of data (Frischer and Fillwalk 2012: 53) that makes up so large a component of the model as an effective tool in expanding empirical and interpretive methodologies. New initiatives need to be undertaken to alter the way these digital records are curated and accessed. One attempt to address this need is the newly formed *Digital Applications in Archaeology and Cultural Heritage* (DAACH) *Journal*. DAACH aims to publish 3D models in a peer reviewed digital journal. Each model accepted for publication requires "metadata, documentation, and a related article, explaining the history of the subject and its state of preservation, as well as an account of the modeling project itself" (Frischer 2013b). The creation of a journal tailored to a growing media may help to standardize presentation and provide long-term curation of digital models comparable to that of textual publications.

Conclusions: 3D in the Field

The many potential uses and benefits of 3D archaeologies are most fully realized by their inclusion throughout the archaeological process. Integration of digital recordation and modeling into field practices builds a tangible narrative of archaeological practices (Earl 2013: 236). For example, computer models can replicate the particular ways of seeing employed by archaeologists in the field through their utilization as rich text interpretive tools (ibid.: 227). Rigidly structured 3D visualizations can specifically convey particular points of view that were deemed significant in generating meaningful interpretations by archaeologists in the field. Active engagement between field and digital processes therefore creates not only tools to discover and convey interpretations, but also to view those discoveries critically. The integration of these two often-separated research methods also facilitates more direct interaction and therefore increased understanding of 3D technologies for non-specialist archaeologists. Wider understanding of the construction and application of such methodologies and the increased ability to critique one's own processes are key to avoiding the abdication of authority to poorly understand technological tools that Huggett sees as a major concern (2004: 83).

Much virtual archaeology has been completely separated from the research context and the exegesis of data (Forte 2008: 96) and therefore has diminished potential to be critically engaged. Interpretation cannot, however, begin after visualizations and models have been completed, but rather is a constant and fluid process present in all phases of archaeological endeavors (Cripps et al. 2006: 35). The situation of 3D archaeology outside of the post-excavation lab work phase of an archaeological project is therefore necessary to fully realize the potential for new ways of seeing and interpreting that computer models create. The process of learning to see archaeologically is gradual and cumulatively built through experience in the various settings of the field (Bradley 2003: 155), and a similar process is necessary to build competency with new digital methodologies. Just as archaeologists learn to "see" by dwelling within the field of practice or a particular site, dwelling within the virtual environments created via 3D archaeology enables an expansion and extension of ways of seeing (Cripps et al. 2006: 26).

Not only does a prolonged engagement with 3D representations help facilitate nuanced understanding of them, it also contributes to the overall quality and effectiveness thereof. A key component in building accurate 3D environments is the ability to check virtual constructions against the real world phenomena they record and recreate (Guidi et al. 2014: 11). Given the aim of creating metrically accurate visualizations of real world spaces in 3D archaeology, the ability to verify accuracy against those real objects is a key component of the process. This ability to directly compare real world experience with digitalization is also invaluable to the use of 3D archaeologies as interpretive tools, where again careful practice is needed in order to not cede authority to the hidden processes and assumptions of software code and hardware functionality. The construction of digital workflows situated within archaeological fieldwork also enables a multi-directional engagement with digital models. Rich ontologies for 3D archaeology include user feedback, data observation, and the interaction of acquisition and interpretation activities in order to generate new knowledge from digital hermeneutic cycles (Forte 2014: 2).

The production of 3D models at the PARP:PS 2014 field season illustrates the feasibility and low cost (both in expense, labor, and expertise) of incorporating 3D archaeology into the modern archaeological process. The methodologies employed here are but two of numerous possible avenues to construct 3D thinking spaces and to add new layers of depth to site and contextual recordation. These new layers consist of both increased detail in spatial data, such as the ability to use PhotoScan models as photogrammetric reconstructions of archaeological space, as well as the preservation (or otherwise creation) of new methods of visual heuristic experience and exploration.

FIGURES

Figure 1 - "Miniaturization" in a point cloud with detail (top) and full extent (bottom)

Figure 2 - Extent of scanned area. Modified from Ellis et al. 2011.

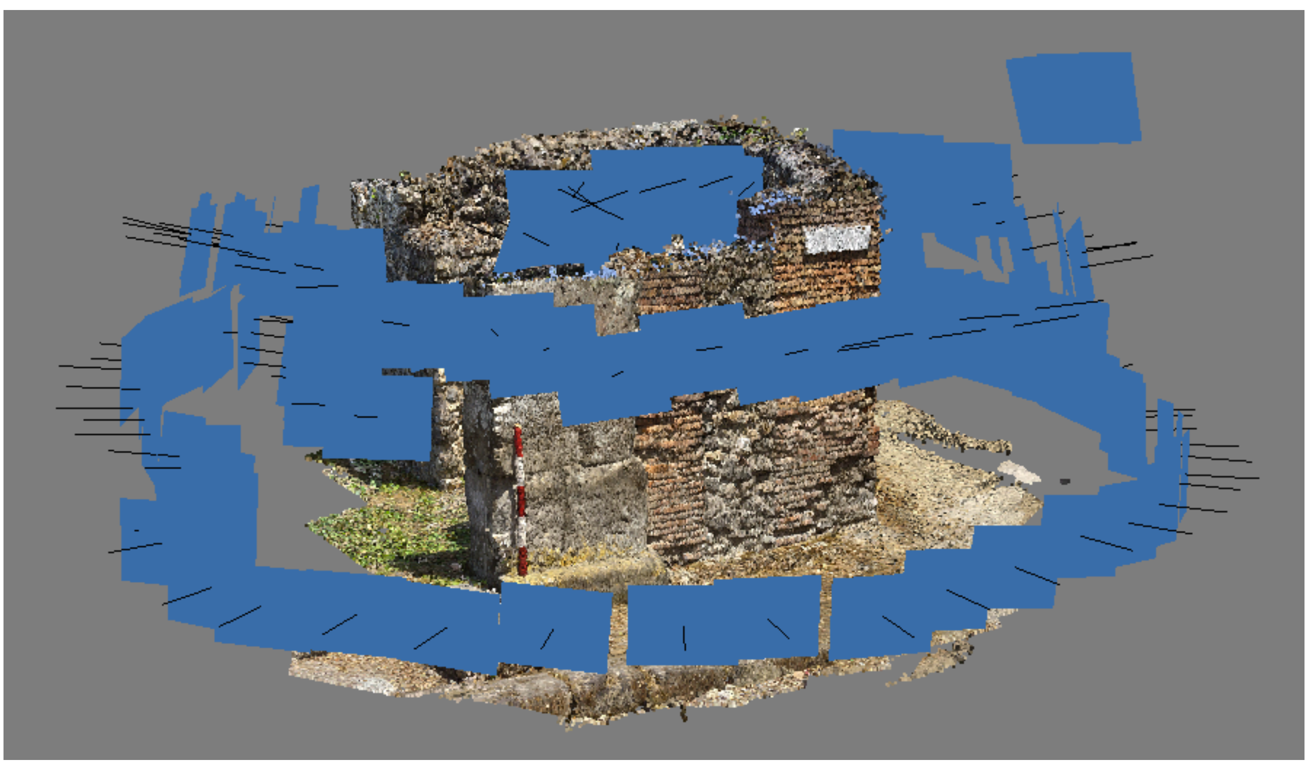

Figure 3 - PhotoScan model with location and direction of constituent photographs

Figure 4 - PhotoScan model with blocked doorway removed.

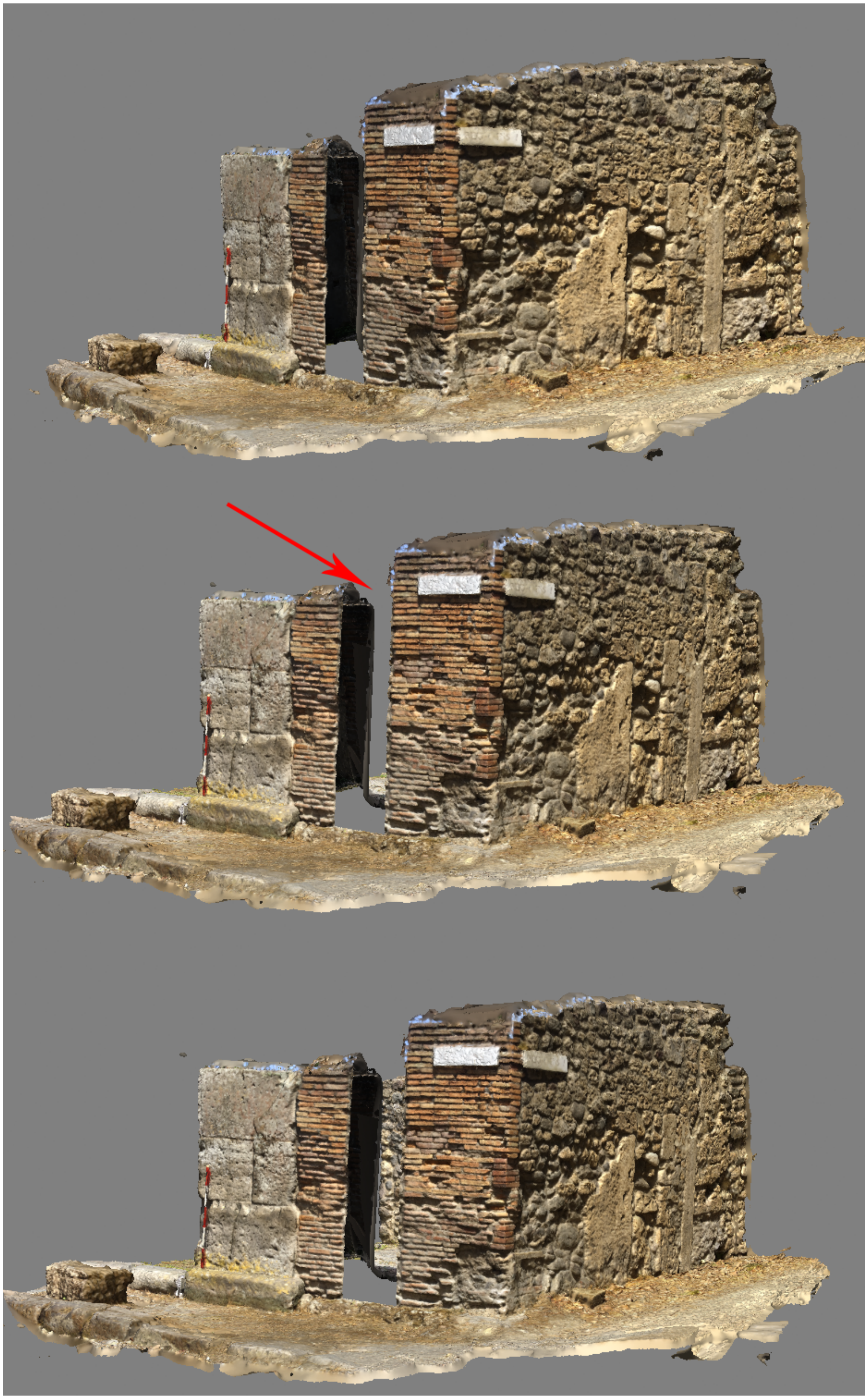

Figure 5 - Lines of sight through cleared doorway.

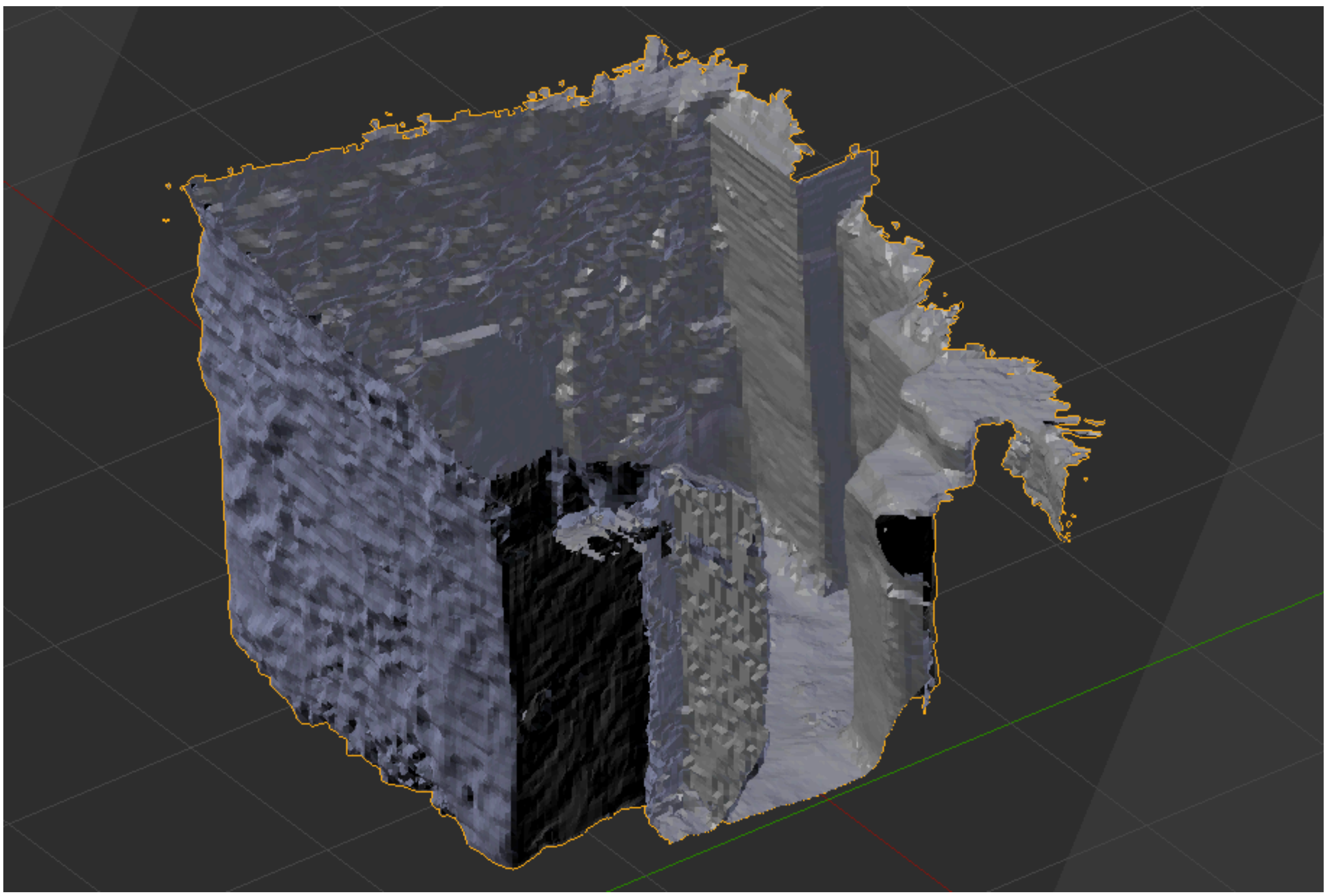

Figure 6 - Structure Sensor with Skanect model.

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